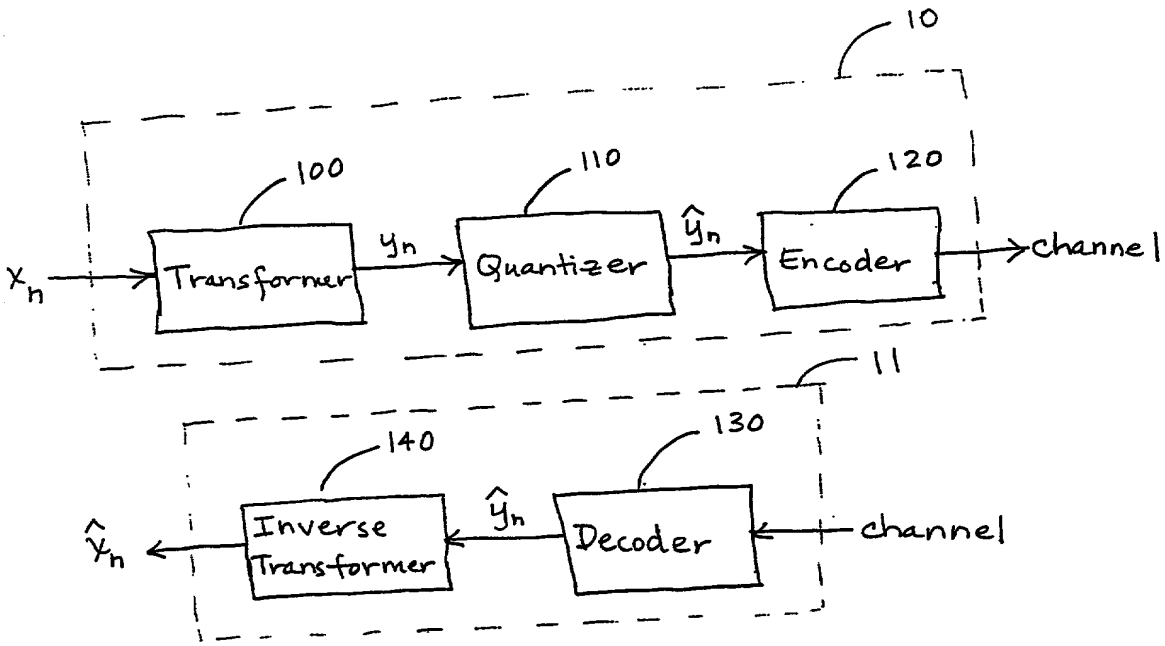
10
100
110
120
x_n
Transformer
y_n
Quantizer
$\hat{y}_n$
Encoder
channel
11
140
130
$\hat{x}_n$
Inverse Transformer
$\hat{y}_n$
Decoder
channel

Fig 1

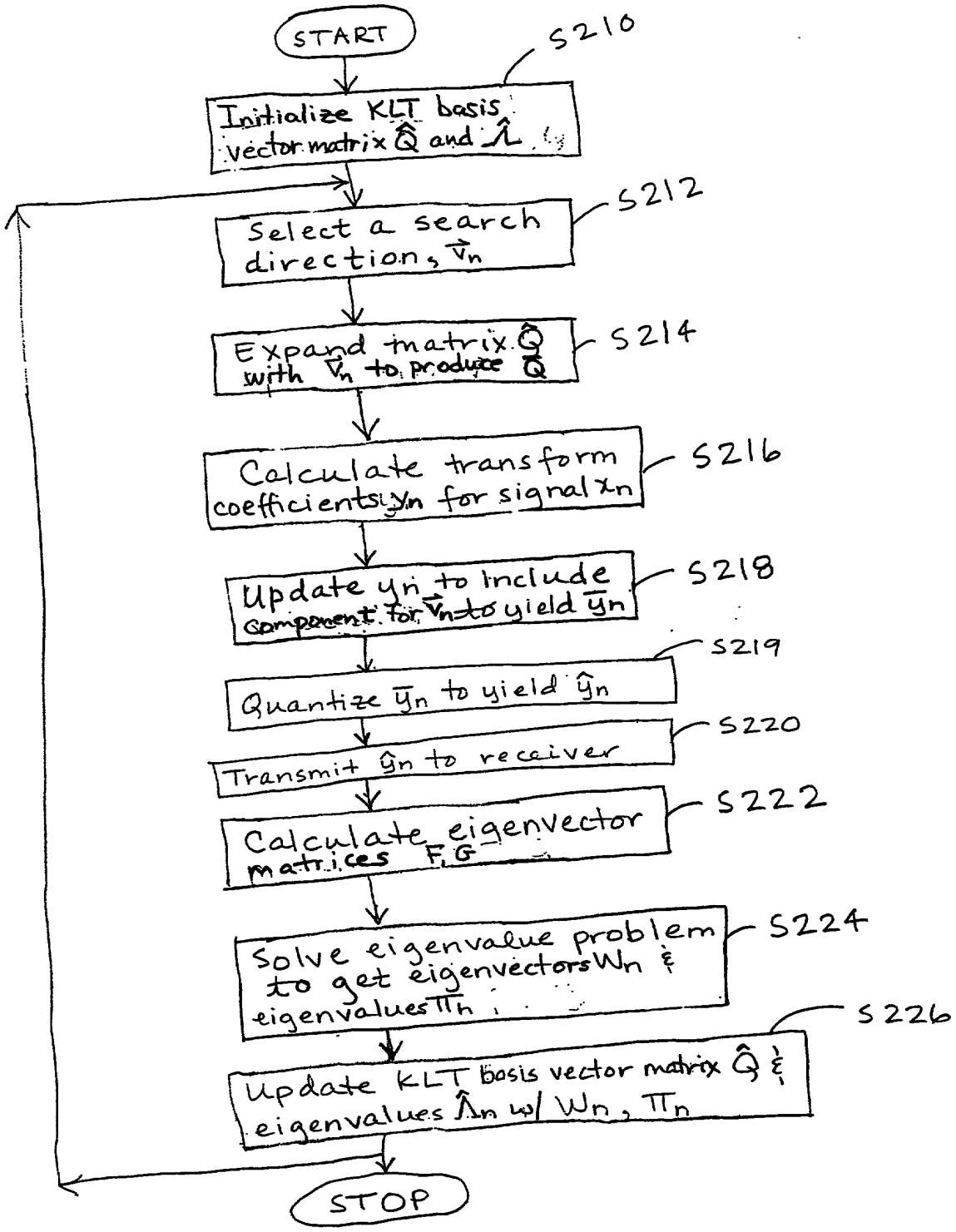
START
S210
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
S212
Select a search direction, $\vec{v}_n$
S214
Expand matrix $\hat{Q}$ with $\vec{v}_n$ to produce $\bar{Q}$
S216
Calculate transform coefficients y_n for signal x_n
S218
Update y_n to include component for $\vec{v}_n$ to yield $\bar{y}_n$
S219
Quantize $\bar{y}_n$ to yield $\hat{y}_n$
S220
Transmit $\hat{y}_n$ to receiver
S222
Calculate eigenvector matrices F, G
S224
Solve eigenvalue problem to get eigenvectors W_n & eigenvalues Π_n
S226
Update KLT basis vector matrix $\hat{Q}$ & eigenvalues $\hat{\Lambda}_n$ w/ W_n, Π_n
STOP

Fig 2A

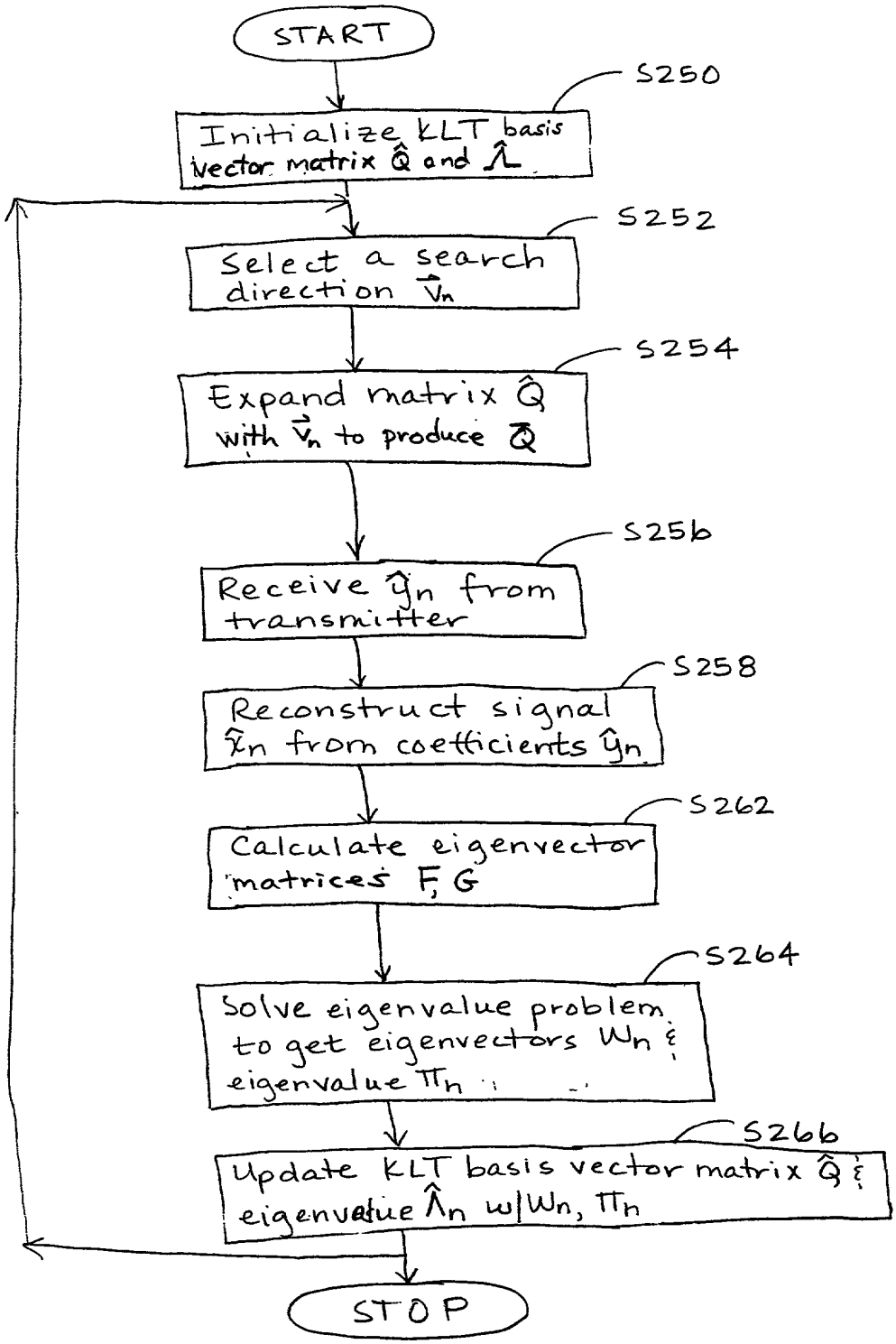
START
S250
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
S252
Select a search direction $\vec{v}_n$
S254
Expand matrix $\hat{Q}$ with $\vec{v}_n$ to produce $\vec{Q}$
S256
Receive $\hat{y}_n$ from transmitter
S258
Reconstruct signal $\hat{x}_n$ from coefficients $\hat{y}_n$
S262
Calculate eigenvector matrices F, G
S264
Solve eigenvalue problem to get eigenvectors W_n & eigenvalue Π_n
S266
Update KLT basis vector matrix $\hat{Q}$ & eigenvalue $\hat{\Lambda}_n$ w/W_n, Π_n
STOP

Fig 2B

transmitter

$\hat{Q}_0 = I_N(:, 1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

$\bar{Q}_n = [\hat{Q}_{n-1} \;\; v_n]$

$y_n = \hat{Q}_{n-1}^T x_n$

$\bar{y}_n = [y_n^T \;\; x_n^T v_n]^T$

$\hat{y}_n = \Delta(\bar{y}_n)$

transmit $\hat{y}_n$ to receiver

$F = r\bar{Q}_n^T \hat{Q}_{n-1} \Lambda_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

$G = \bar{Q}_n^T \bar{Q}_n$

Solve $FW_n = GW_n\Pi_n$ for W_n, Π_n

$\hat{Q}_n = \bar{Q}_n W_n(:, 1:r)$

$\hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

end

receiver

$\hat{Q}_0 = I_N(:, 1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

$\bar{Q}_n = [\hat{Q}_{n-1} \;\; v_n]$

wait for $\hat{y}_n$

$\hat{x}_n = \hat{Q}_{n-1} \hat{y}_n(1:r)$

$F = r\bar{Q}_n^T \hat{Q}_{n-1} \hat{\Lambda}_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

$G = \bar{Q}_n^T \bar{Q}_n$

Solve $FW_n = GW_n\Pi_n$ for W_n, Π_n

$\hat{Q}_n = \bar{Q}_n W_n(:, 1:r)$

$\hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

end

Figure 2C

20040135560

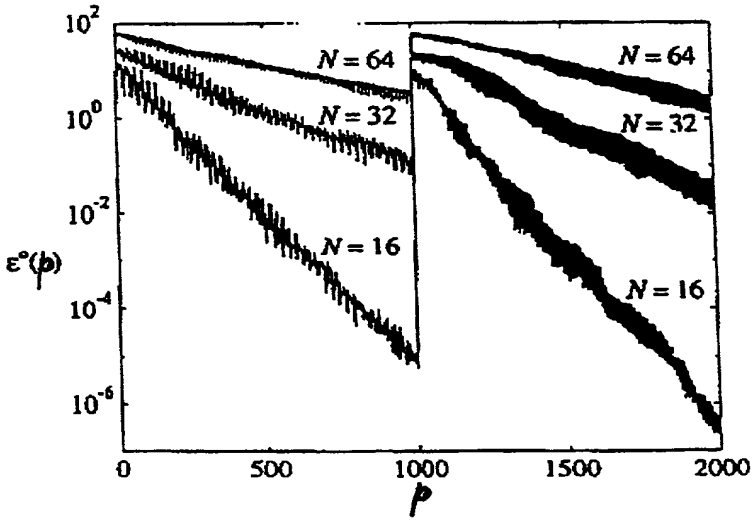

Fig 3

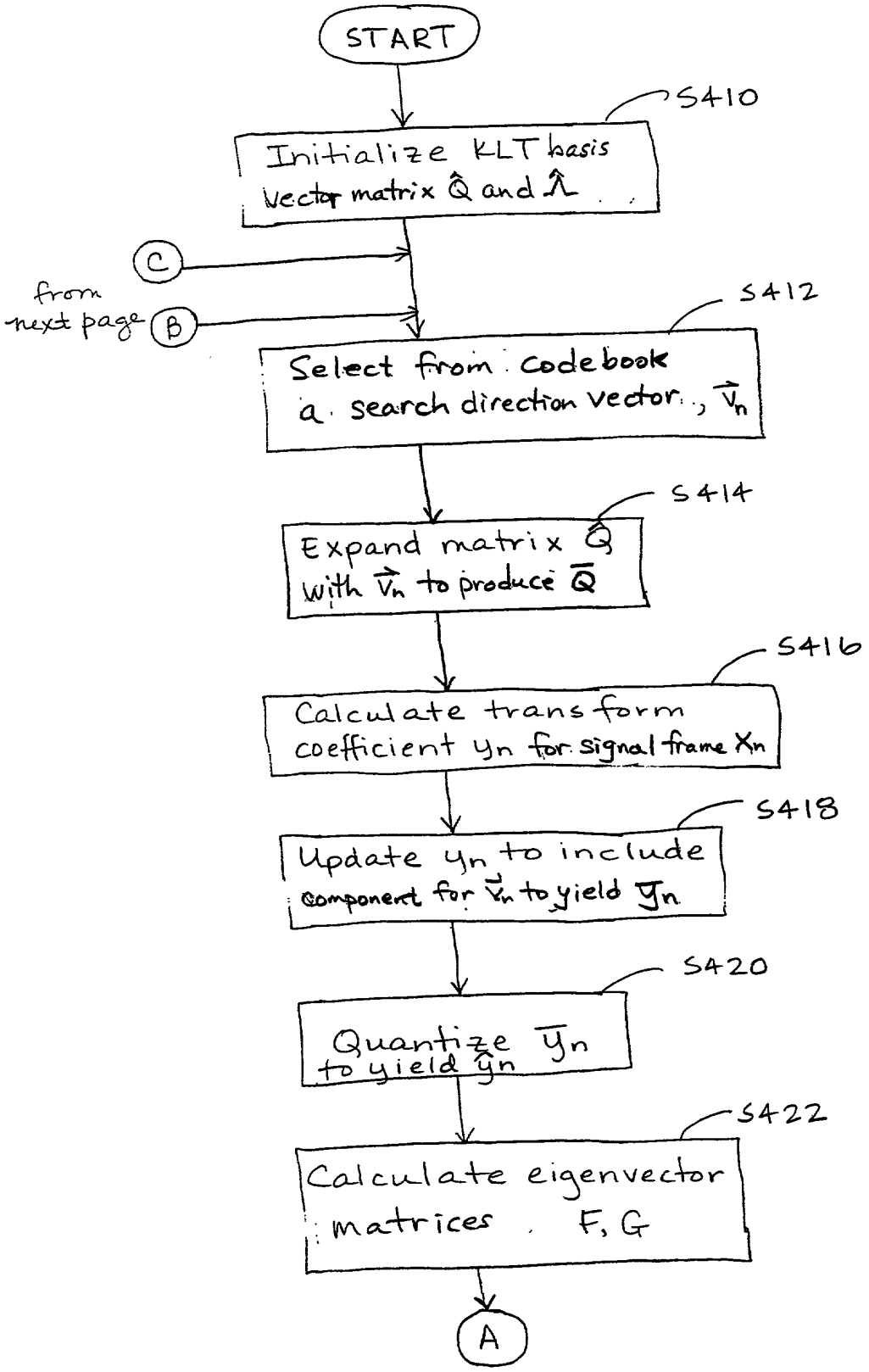
START
S410
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
C
from next page
B
S412
Select from codebook a search direction vector, $\vec{v}_n$
S414
Expand matrix $\bar{Q}$ with $\vec{v}_n$ to produce $\bar{Q}$
S416
Calculate transform coefficient y_n for signal frame X_n
S418
Update y_n to include component for $\vec{v}_n$ to yield $\bar{y}_n$
S420
Quantize $\bar{y}_n$ to yield $\hat{y}_n$
S422
Calculate eigenvector matrices F, G
A

Fig 4A

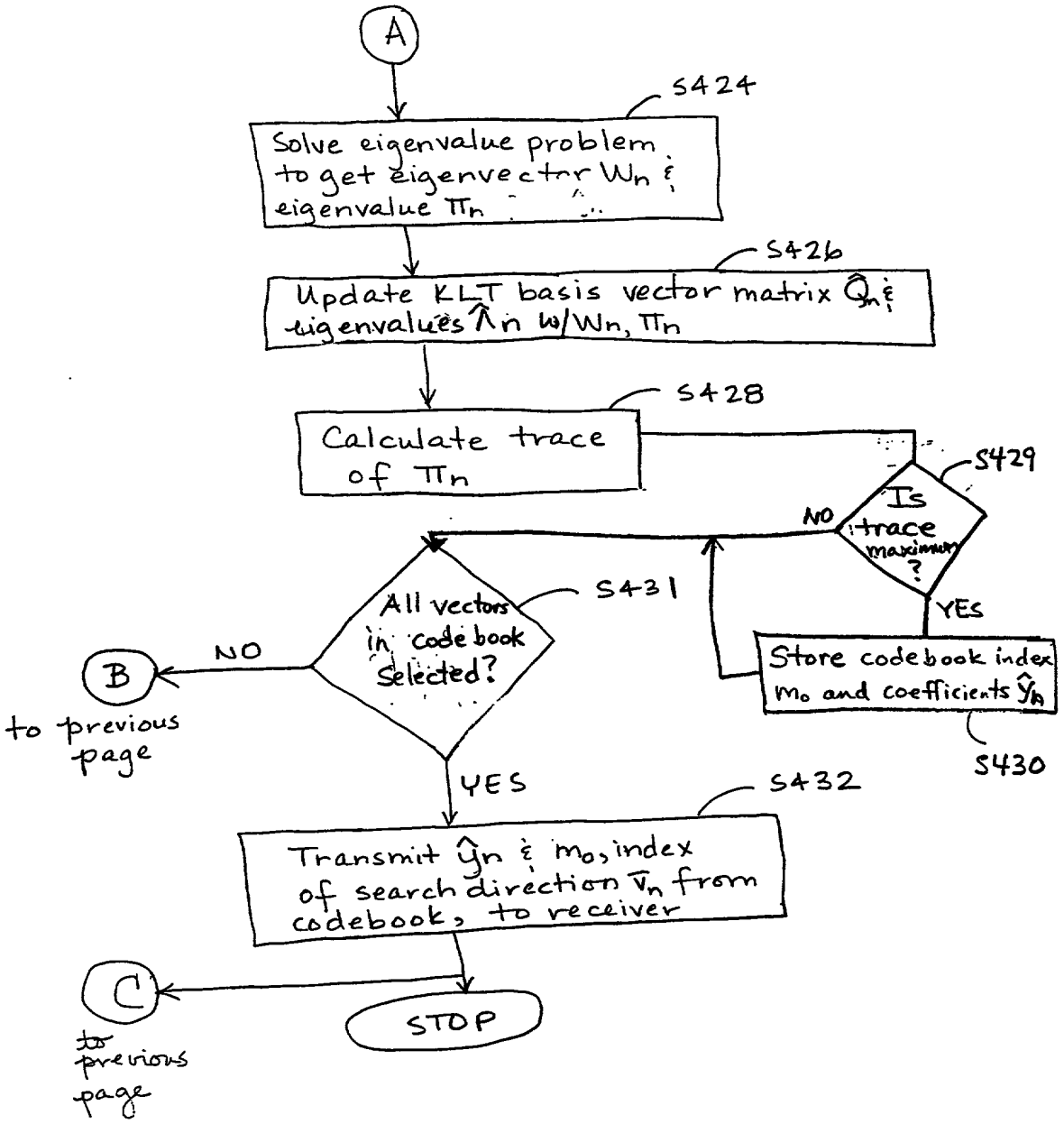
A
S424
Solve eigenvalue problem to get eigenvector W_n & eigenvalue Π_n
S426
Update KLT basis vector matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$ w/ W_n, Π_n
S428
Calculate trace of Π_n
S429
Is trace maximum?
NO
YES
S431
All vectors in codebook selected?
NO
B
to previous page
YES
Store codebook index m_o and coefficients $\hat{y}_n$
S430
S432
Transmit $\hat{y}_n$ & m_o, index of search direction $\bar{v}_n$ from codebook, to receiver
C
to previous page
STOP

Fig 4A (CONT.)

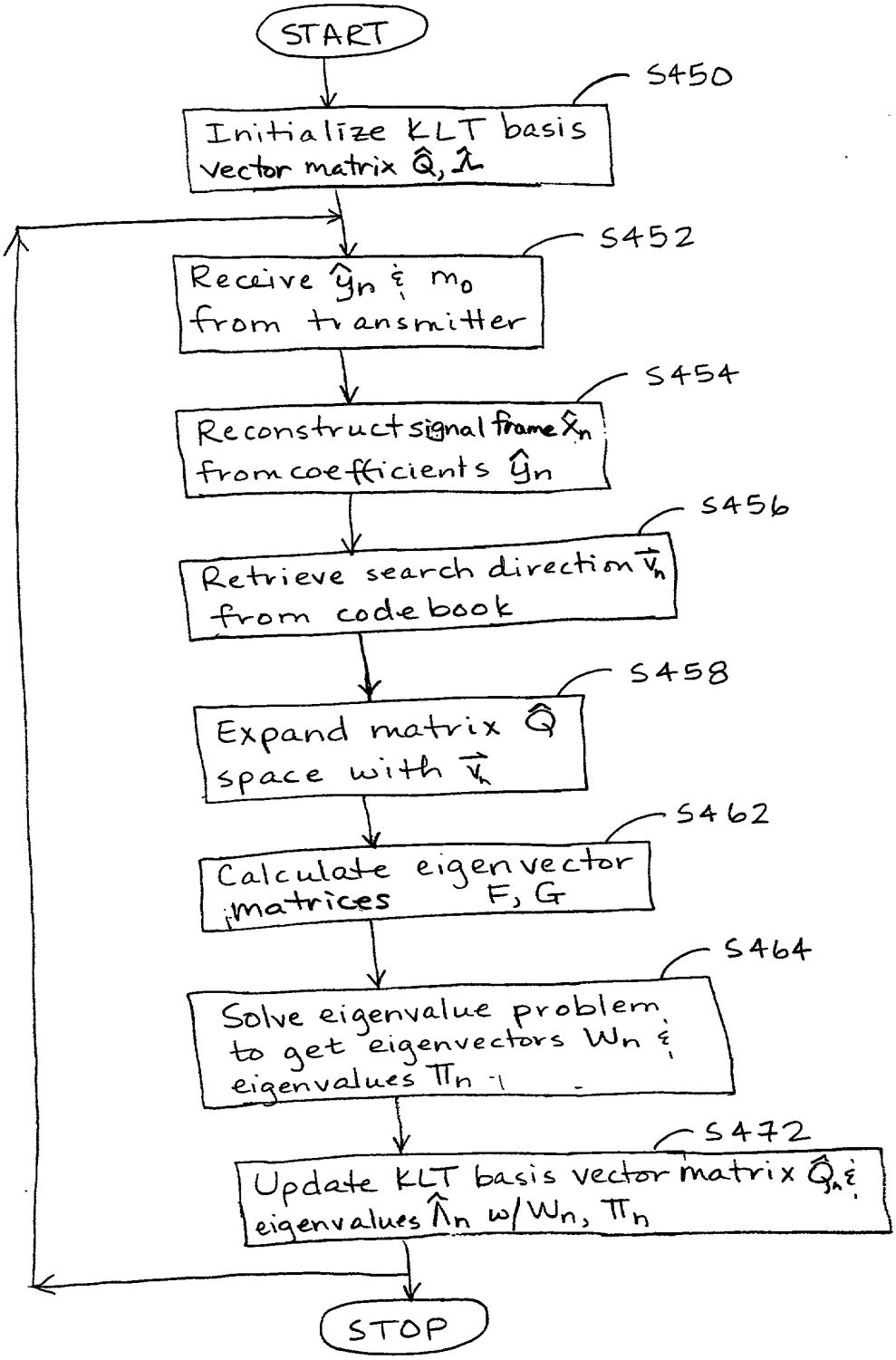
START
S450
Initialize KLT basis vector matrix $\hat{Q}$, $\hat{\Lambda}$
S452
Receive $\hat{y}_n$ & m_0 from transmitter
S454
Reconstruct signal frame $\hat{x}_n$ from coefficients $\hat{y}_n$
S456
Retrieve search direction $\vec{v}_n$ from codebook
S458
Expand matrix $\hat{Q}$ space with $\vec{v}_n$
S462
Calculate eigenvector matrices F, G
S464
Solve eigenvalue problem to get eigenvectors W_n & eigenvalues Π_n
S472
Update KLT basis vector matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$ w/ W_n, Π_n
STOP

Fig 4B

Figure 4C

transmitter

$\hat{Q}_0 = I_N(:, 1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

  $T_{max} = 0$

  for $m = 1, \ldots, M$

    $v_n = V(:, m)$

    $\bar{Q} = [\hat{Q}_{n-1} \; v_n]$

    $y_n = \hat{Q}_{n-1}^T x_n$

    $\bar{y}_n = [y_n^T \; x_n^T v_n]^T$

    $\hat{y}_n = \Delta(\bar{y}_n)$

    $F = \gamma \bar{Q}^T \hat{Q}_{n-1} \hat{\Lambda}_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

    $G = \bar{Q}_n^T \bar{Q}_n$

    solve $FW_n = GW_n\Pi_n$ for W_n, Π_n

    $\hat{Q}_n = \bar{Q}_n W_n(:, 1:r)$

    $\hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

    $T = \text{trace}(\Pi_n(1:r, 1:r))$

    if $T > T_{max}$

      $T_{max} = T$

      $m_0 = m$

      $\hat{y}_n^* = \hat{y}_n$

    end

  end

  $\hat{y}_n = \hat{y}_n^*$

  transmit $\hat{y}_n, m_0$ to receiver

end

receiver

$\hat{Q}_0 = I_N(:, 1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

  wait for $\hat{y}_n, m_0$

  $\hat{x}_n = \hat{Q}_{n-1} \hat{y}_n(1:r)$

  $v_n = V(:, m_0)$

  $\bar{Q}_n = [\hat{Q}_{n-1} \; v_n]$

  $F = \gamma \bar{Q}^T \hat{Q}_{n-1} \hat{\Lambda}_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

  $G = \bar{Q}_n^T \bar{Q}_n$

  solve $FW_n = GW_n\Pi_n$ for W_n, Π_n

  $\hat{Q}_n = \bar{Q}_n W_n(:, 1:r)$

  $\hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

end

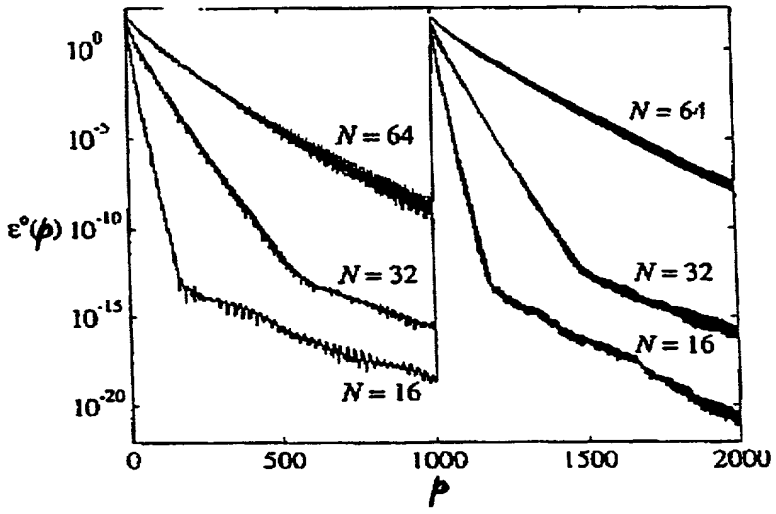
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-20}
$\varepsilon^{\circ}(\phi)$
$N = 64$
$N = 32$
$N = 16$
$N = 64$
$N = 32$
$N = 16$
0
500
1000
1500
2000
ϕ

Fig 5

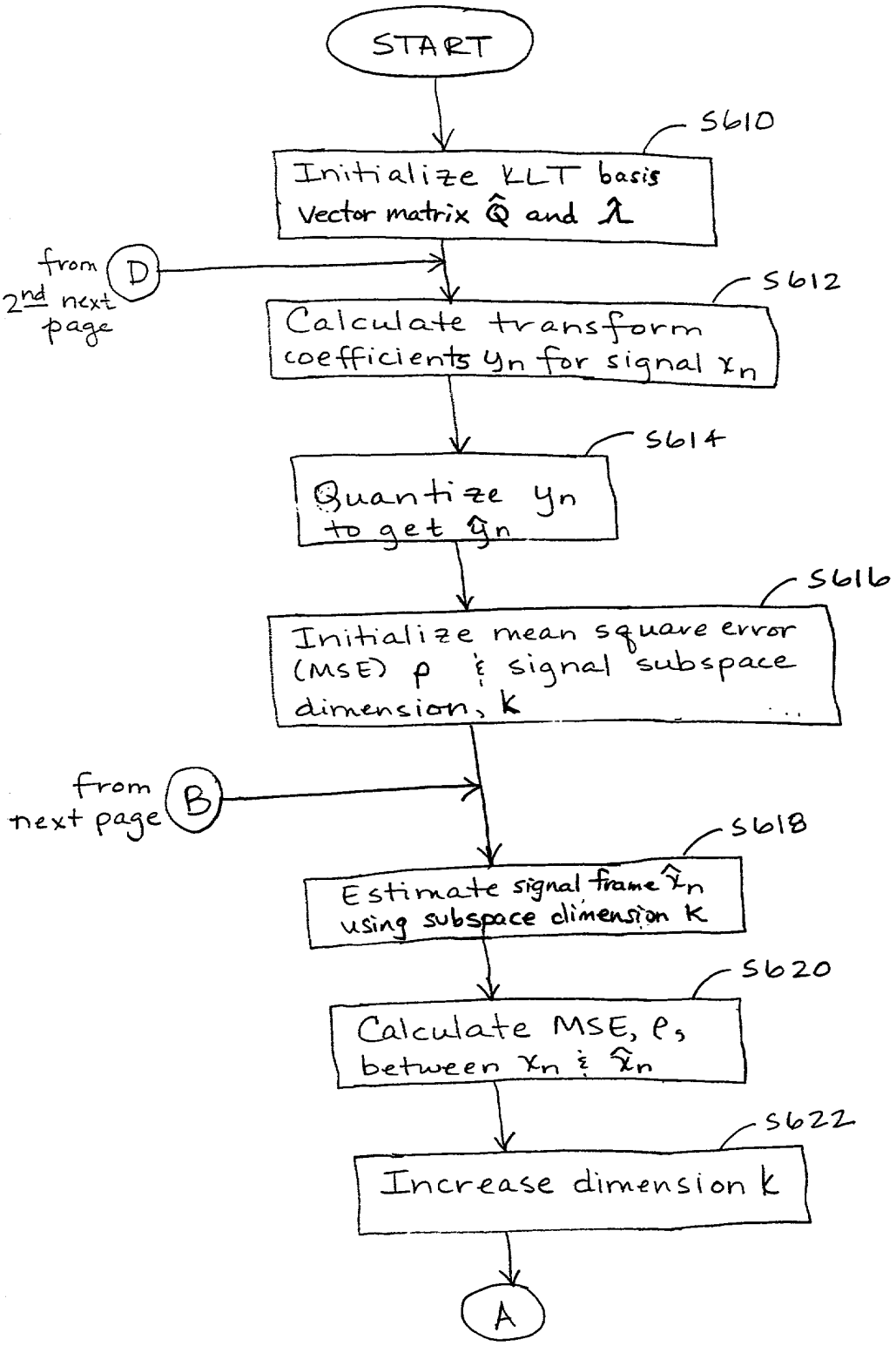
START
S610
Initialize KLT basis Vector matrix $\hat{Q}$ and $\hat{\lambda}$
from D 2nd next page
S612
Calculate transform coefficients y_n for signal x_n
S614
Quantize y_n to get $\hat{y}_n$
S616
Initialize mean square error (MSE) ρ & signal subspace dimension, k
from B next page
S618
Estimate signal frame $\hat{x}_n$ using subspace dimension k
S620
Calculate MSE, ρ_s between x_n & $\hat{x}_n$
S622
Increase dimension k
A

Fig 6A

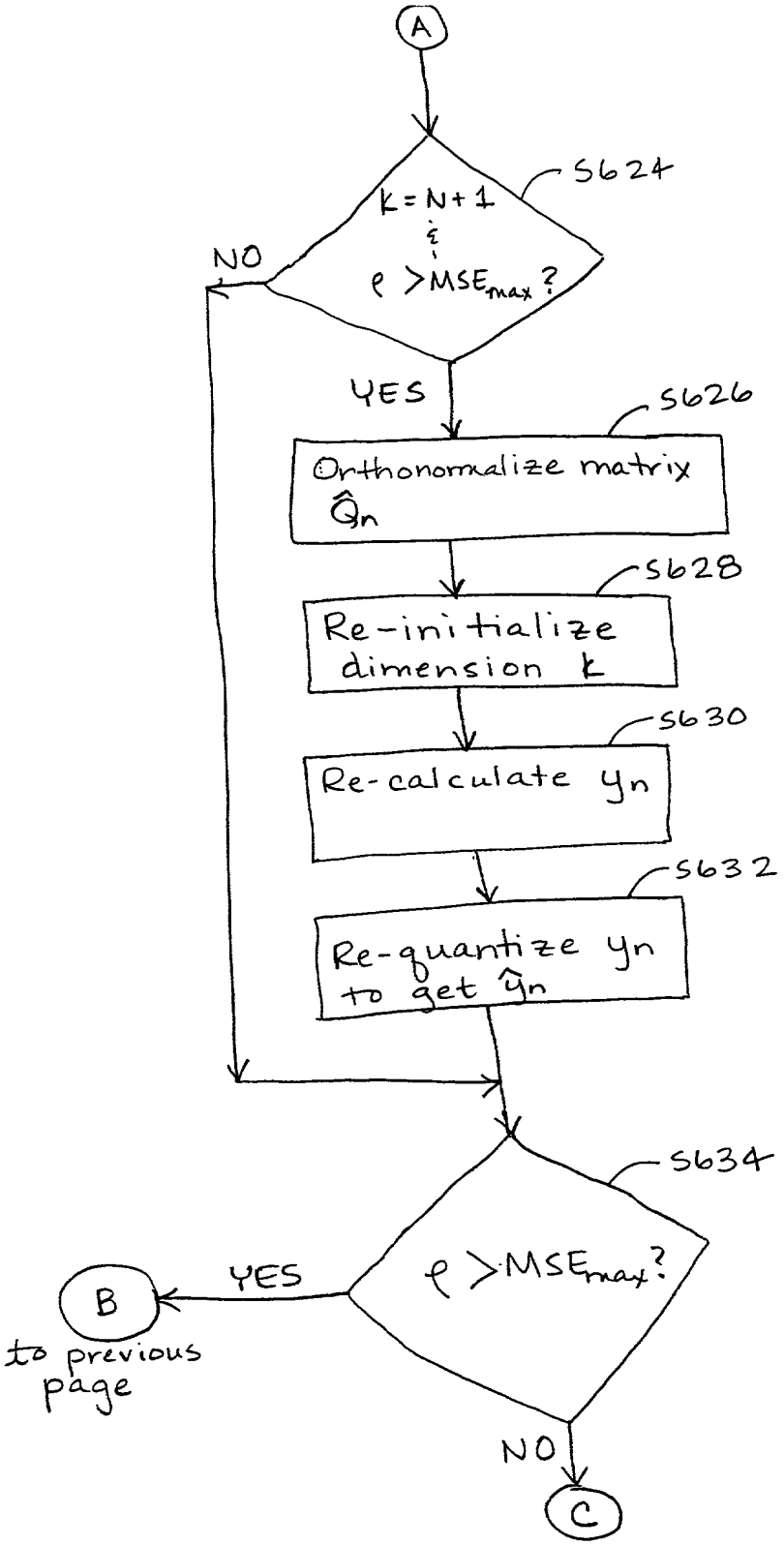
A
S624
k = N+1
ρ > MSE_max ?
NO
YES
S626
Orthonormalize matrix
Q̂n
S628
Re-initialize
dimension k
S630
Re-calculate yn
S632
Re-quantize yn
to get ŷn
S634
ρ > MSE_max ?
YES
B
to previous
page
NO
C

Fig 6A (CONT.)

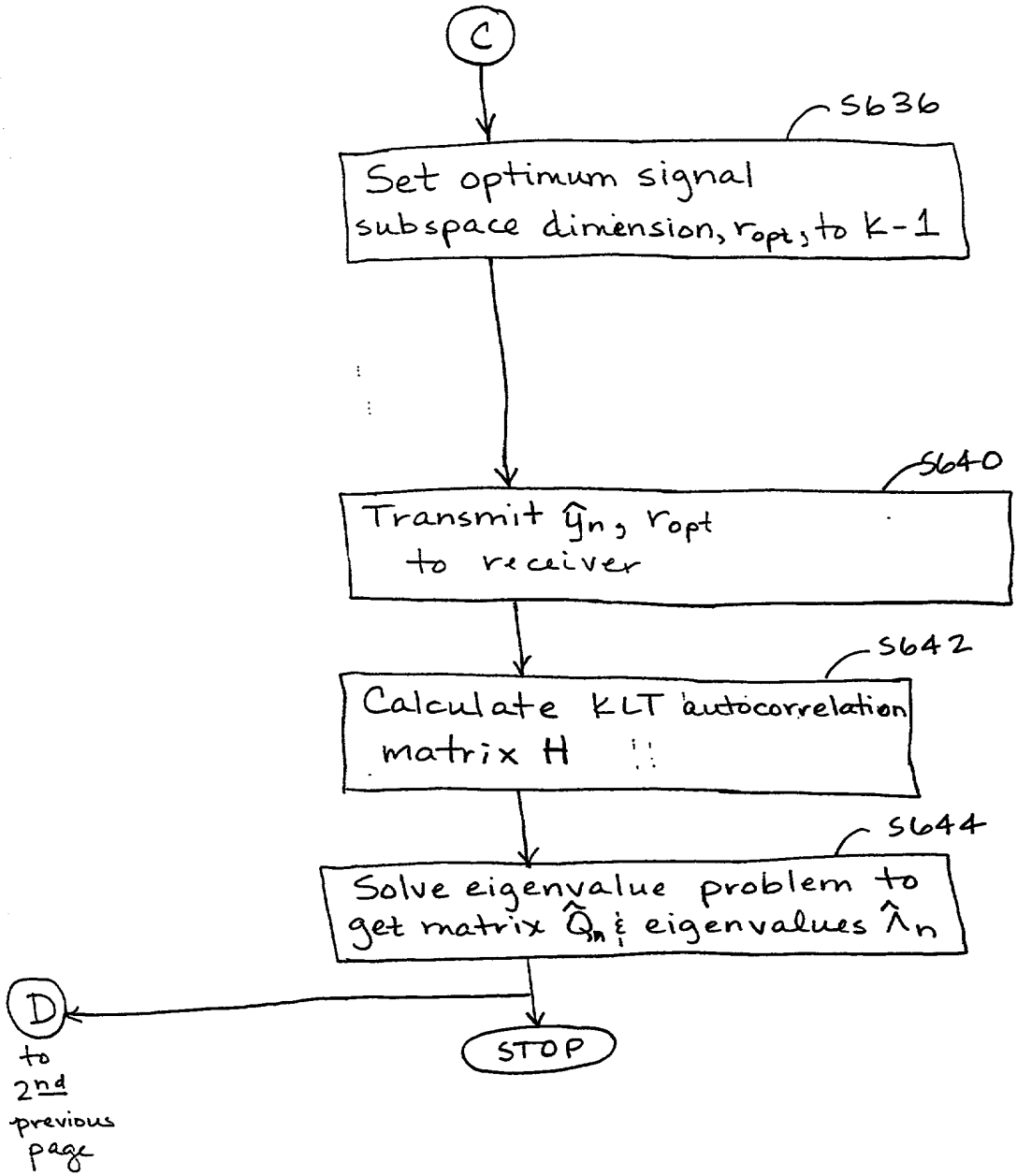
C
S636
Set optimum signal subspace dimension, r_{opt}, to K-1
S640
Transmit $\hat{y}_n$, r_{opt} to receiver
S642
Calculate KLT autocorrelation matrix H
S644
Solve eigenvalue problem to get matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$
D
to 2nd previous page
STOP

Fig 6A (CONT.)

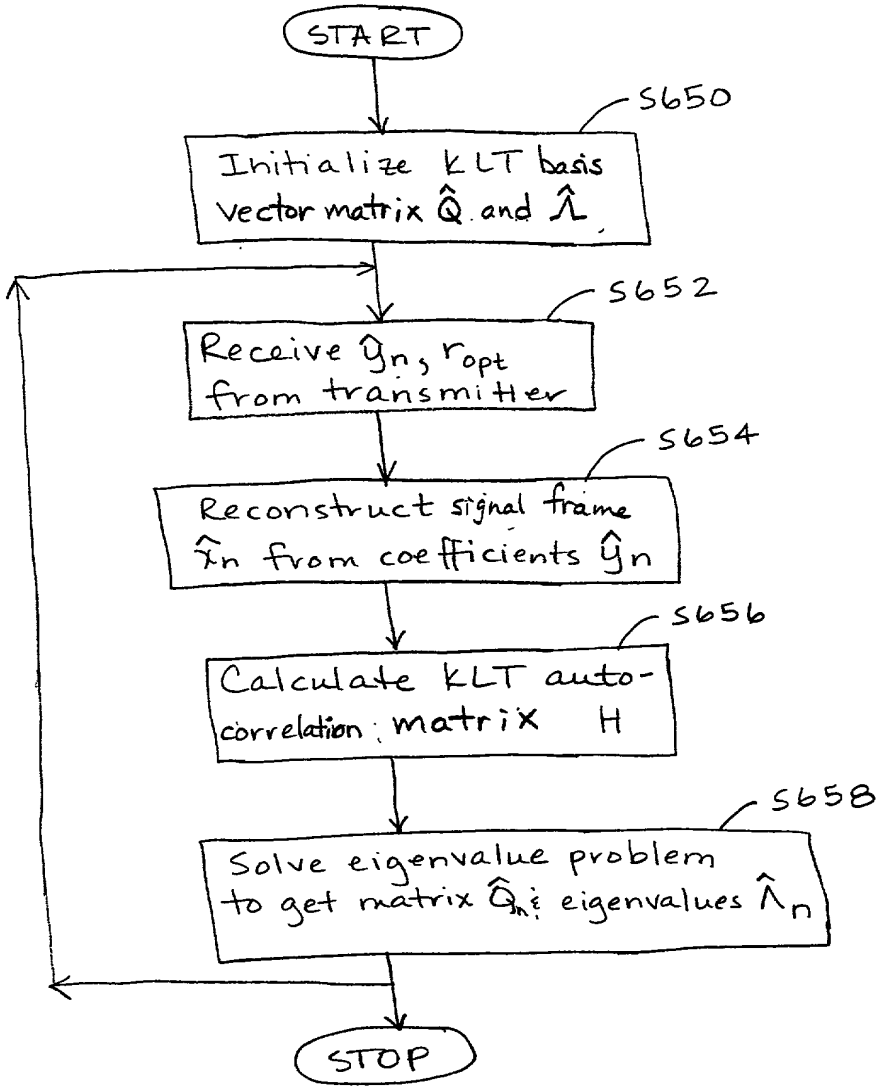
START
S650
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
S652
Receive $\hat{y}_n$, r_{opt} from transmitter
S654
Reconstruct signal frame $\hat{x}_n$ from coefficients $\hat{y}_n$
S656
Calculate KLT auto-correlation matrix H
S658
Solve eigenvalue problem to get matrix $\hat{Q}_n$ eigenvalues $\hat{\Lambda}_n$
STOP

Fig 6B

transmitter

$\hat{Q}_0 = I_N$

$\hat{\Lambda}_0 = I_N$

for $n=1,2,\ldots$

$y_n = \hat{Q}_{n-1}^T x_n$

$\hat{y}_n = \Delta(y_n)$

$\rho = 1$

$K = 1$

while $\rho > MSE_{max}$

$\hat{x}_n = \hat{Q}_{n-1}(:, 1:K)\hat{y}_n(1:K)$;

$\rho = \|\hat{x}_n - x_n\|^2 / \|x_n\|^2$

$K = K+1$

if $K = N+1$ and $\rho > MSE_{max}$

orthonormalize columns of $\hat{Q}_n$

$K = 1$

$y_n = \hat{Q}_{n-1}^T x_n$

$\hat{y}_n = \Delta(y_n)$

end

end

$r_{opt} = K-1$

transmit $\hat{y}_n(1:r_{opt})$, r_{opt} to receiver

$H = \gamma\hat{\Lambda}_{n-1} + \hat{y}_n\hat{y}_n^T$

solve $H\hat{Q}_n = \hat{Q}_n\hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$

end

receiver

$\hat{Q}_0 = I_N$

$\hat{\Lambda}_0 = I_N$

for $n=1,2,\ldots$

wait for $\hat{y}_n(1:r_{opt})$, r_{opt}

$\hat{x}_n = \hat{Q}_{n-1}(:, 1:r_{opt})\hat{y}_n(1:r_{opt})$

$H = \gamma\hat{\Lambda}_{n-1} + \hat{y}_n\hat{y}_n^T$

solve $H\hat{Q}_n = \hat{Q}_n\hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$

end

Figure 6C

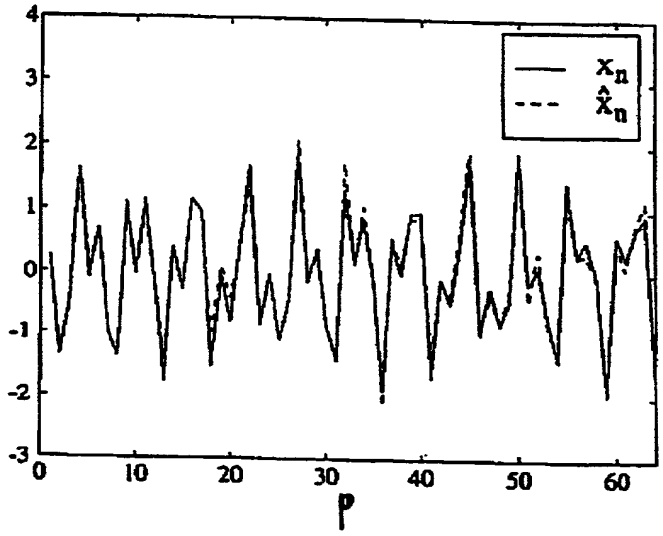

Fig 7

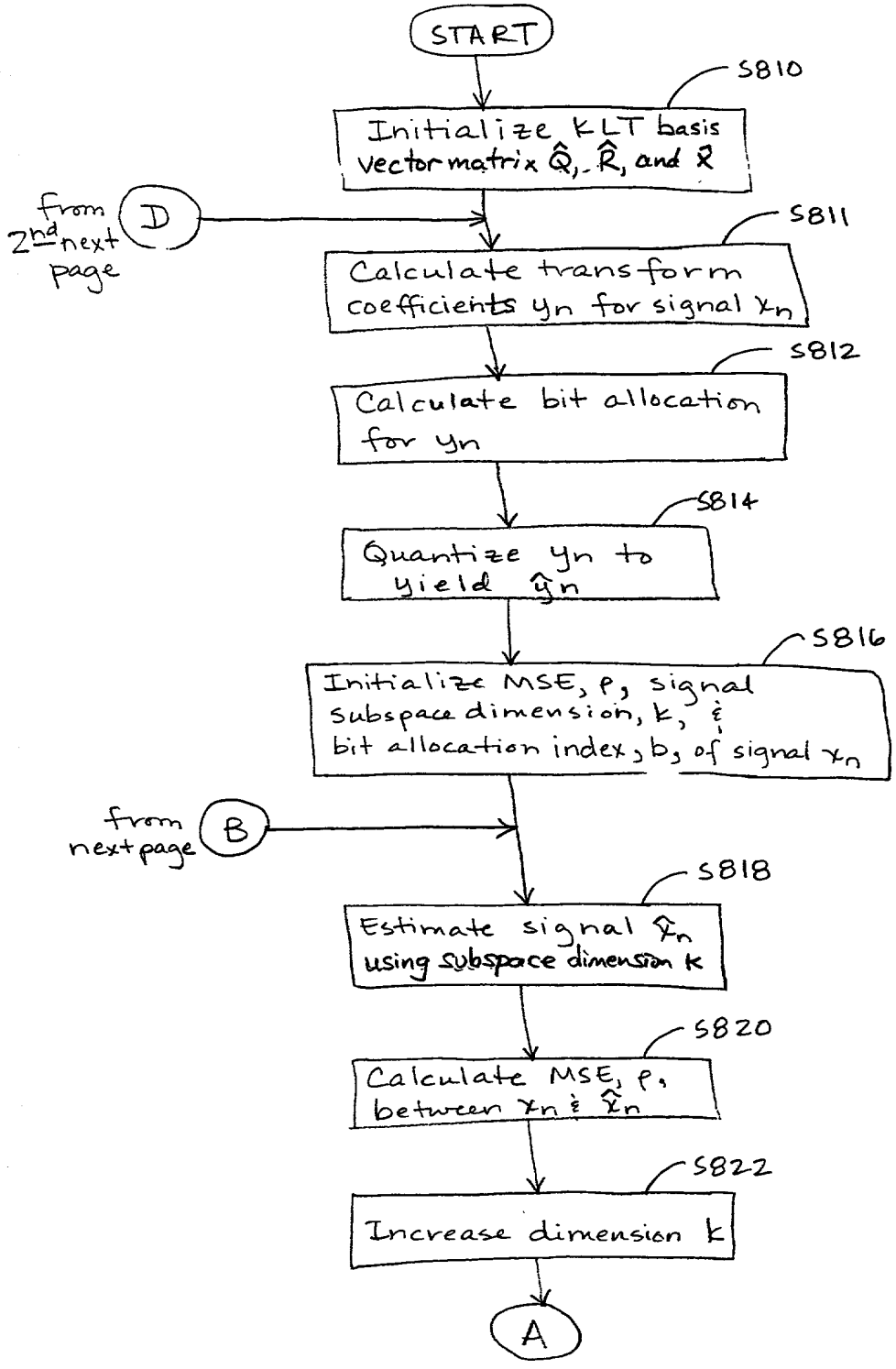

Fig 8A

DOCKET NO: 214576US20

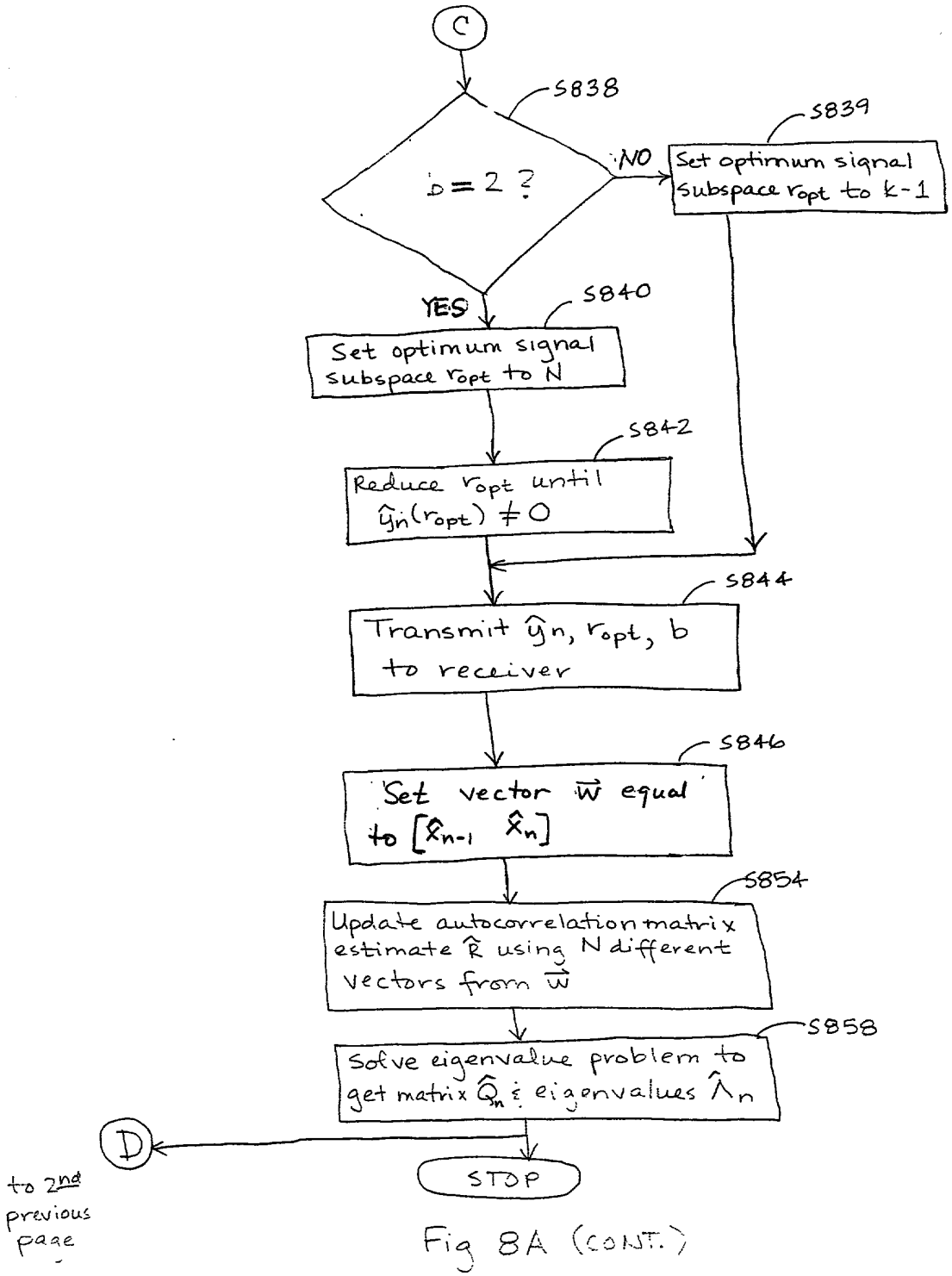
C
S838
b = 2 ?
NO
S839
Set optimum signal subspace r_{opt} to k-1
YES
S840
Set optimum signal subspace r_{opt} to N
S842
Reduce r_{opt} until $\hat{y}_n(r_{opt}) \neq 0$
S844
Transmit $\hat{y}_n$, r_{opt}, b to receiver
S846
Set vector $\vec{w}$ equal to $[\hat{x}_{n-1} \; \hat{x}_n]$
S854
Update autocorrelation matrix estimate $\hat{R}$ using N different vectors from $\vec{w}$
S858
Solve eigenvalue problem to get matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$
D
STOP
to 2nd previous page

Fig 8A (CONT.)

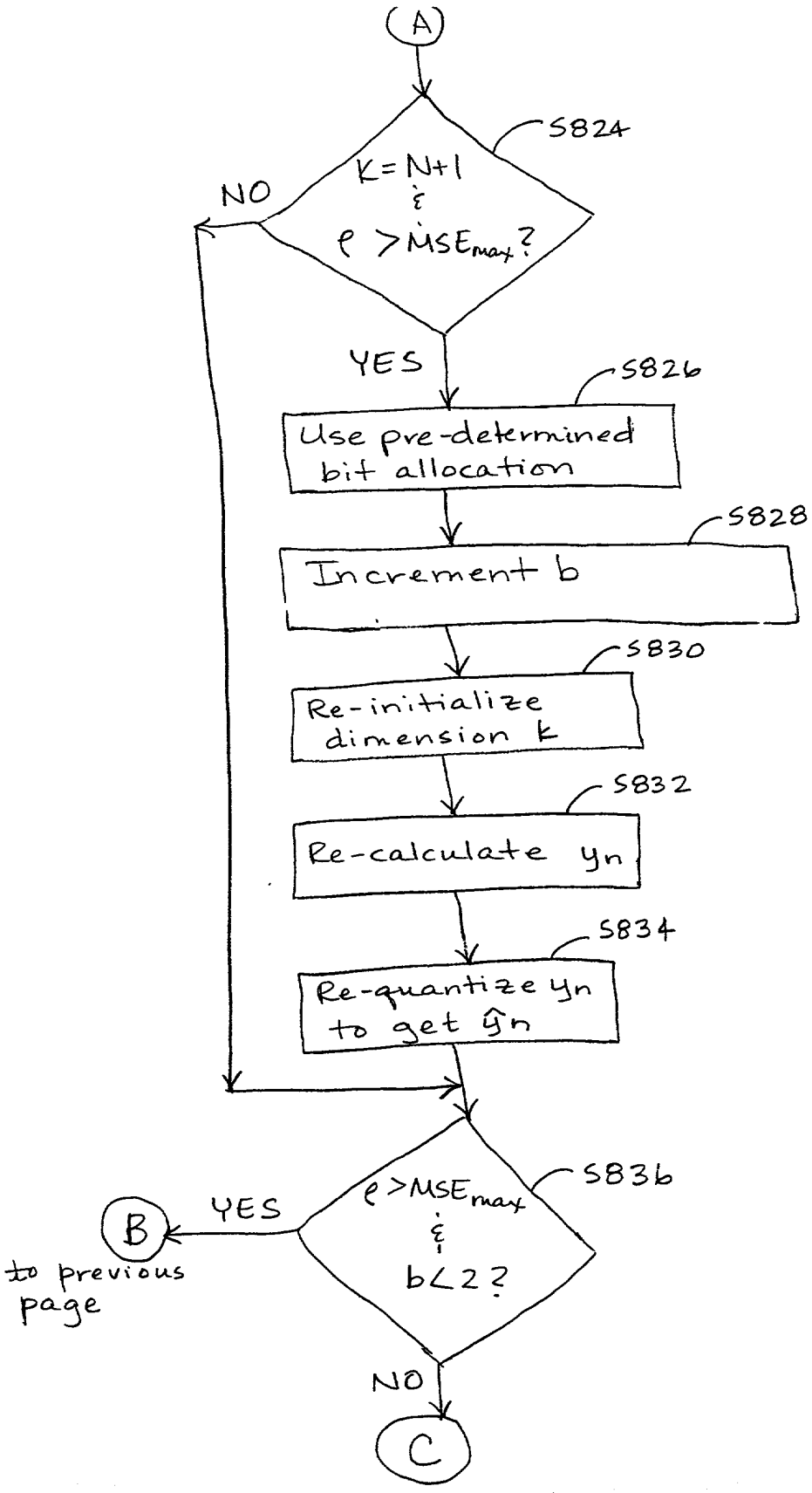
A
S824
K=N+1
&
ρ > MSEmax ?
NO
YES
S826
Use pre-determined bit allocation
S828
Increment b
S830
Re-initialize dimension k
S832
Re-calculate yn
S834
Re-quantize yn to get ŷn
S836
ρ > MSEmax
&
b<2 ?
YES
B
to previous page
NO
C

Fig 8A (CONT.)

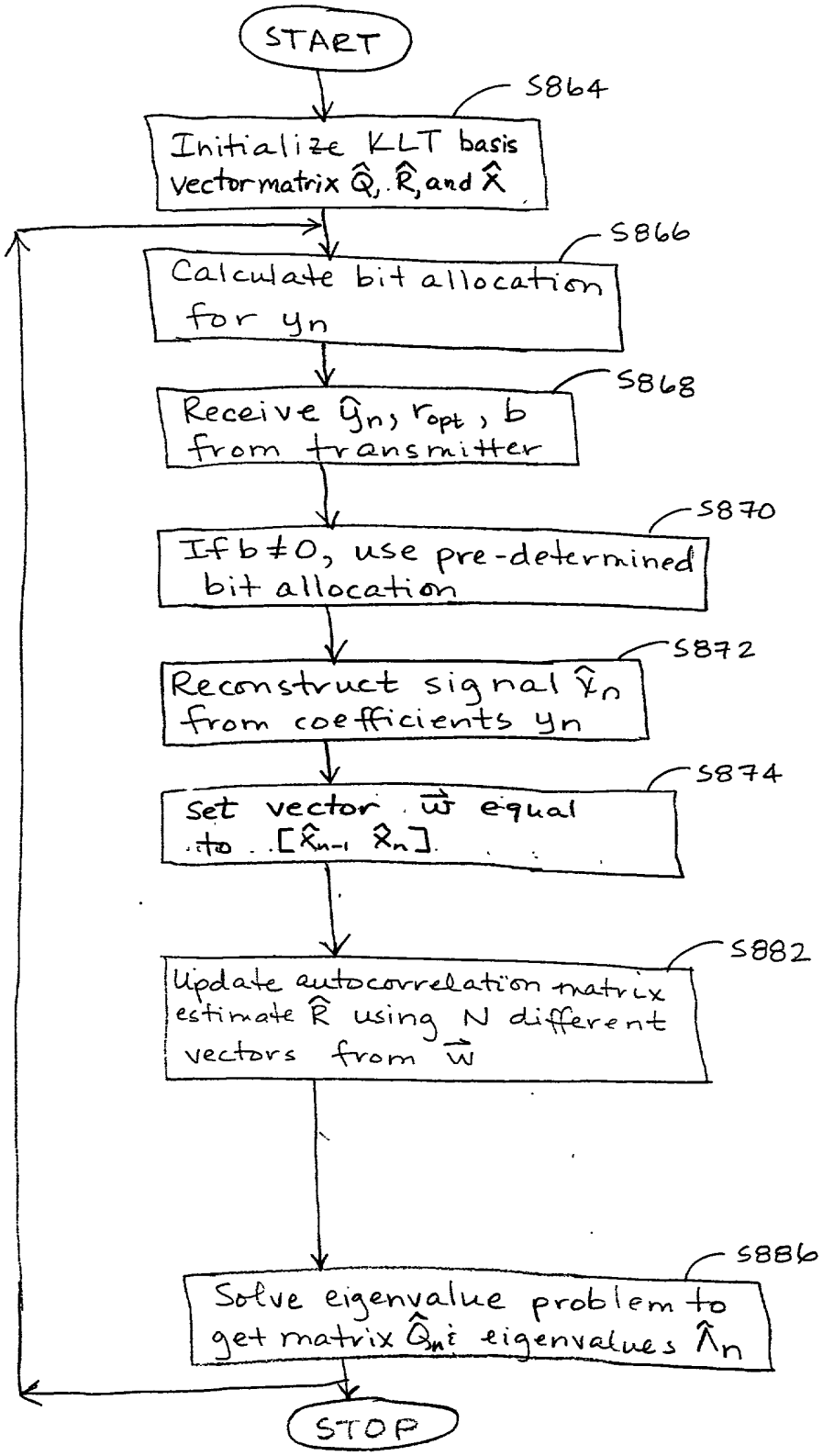

Fig 8B

09/976,053 - 09/26/2003

Figure 8C

transmitter

$\hat{Q}_0 = I_N$
$\hat{x}_0 = 0$
$\hat{\Lambda}_0 = \beta I_N$
for $n=1, 2, \ldots$
  $y_n = \hat{Q}_{n-1}^T x_n$
  $\hat{y}_n = \Delta(y_n)$
  $\rho=1$, $K=1$, $b=0$
  while $\rho > MSE_{max}$ and $b<2$
    $\hat{x}_n = \hat{Q}_{n-1}(:, 1:K)\,\hat{y}_n(1:K)$
    $\rho = \|\hat{x}_n - x_n\|^2$
    $K = K+1$
    if $K=N+1$ and $\rho > MSE_{max}$
      use alternative bit allocation
      $b = b+1$, $K=1$
      $y_n = \hat{Q}_{n-1}^T x_n$
      $\hat{y}_n = \Delta(y_n)$
    end
  end
  if $b \neq 2$, $r_{opt} = K-1$
  if $b=2$
    $r_{opt} = N$
    reduce r_{opt} until $\hat{y}_n(r_{opt}) \neq 0$
  end
  transmit $\hat{y}_n(1:r_{opt})$, r_{opt}, b to receiver
  $w_n = [\hat{x}_{n-1}^T \;\; \hat{x}_n^T]^T$
  $\hat{R}_{n-1,0} = \hat{R}_{n-1}$
  for $m=1,..N$
    $z = w_n(m+1:m+N)$
    $\hat{R}_{n-1,m} = \gamma \hat{R}_{n-1,m-1} + zz^T$
  end
  $\hat{R}_n = \hat{R}_{n-1,N}$
  solve $\hat{R}_n \hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$
end

receiver

$\hat{Q}_0 = I_N$
$\hat{x}_0 = 0$
$\hat{R}_0 = \beta I_N$
for $n=1, 2, \ldots$
  wait for $\hat{y}_n$, r_{opt}, and b
  if $b \neq 0$, use alternative bit allocation
  $\hat{x}_n = \hat{Q}_{n-1}\hat{y}_n$
  $w_n = [\hat{x}_{n-1}^T \;\; \hat{x}_n^T]^T$
  $\hat{R}_{n-1,0} = \hat{R}_{n-1}$
  for $m=1:N$
    $z = w_n(m+1:m+N)$
    $\hat{R}_{n-1,m} = \gamma \hat{R}_{n-1,m-1} + zz^T$
  end
  $\hat{R}_n = \hat{R}_{n-1,N}$
  solve $\hat{R}_n \hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$
end

Docket No. 214576US20

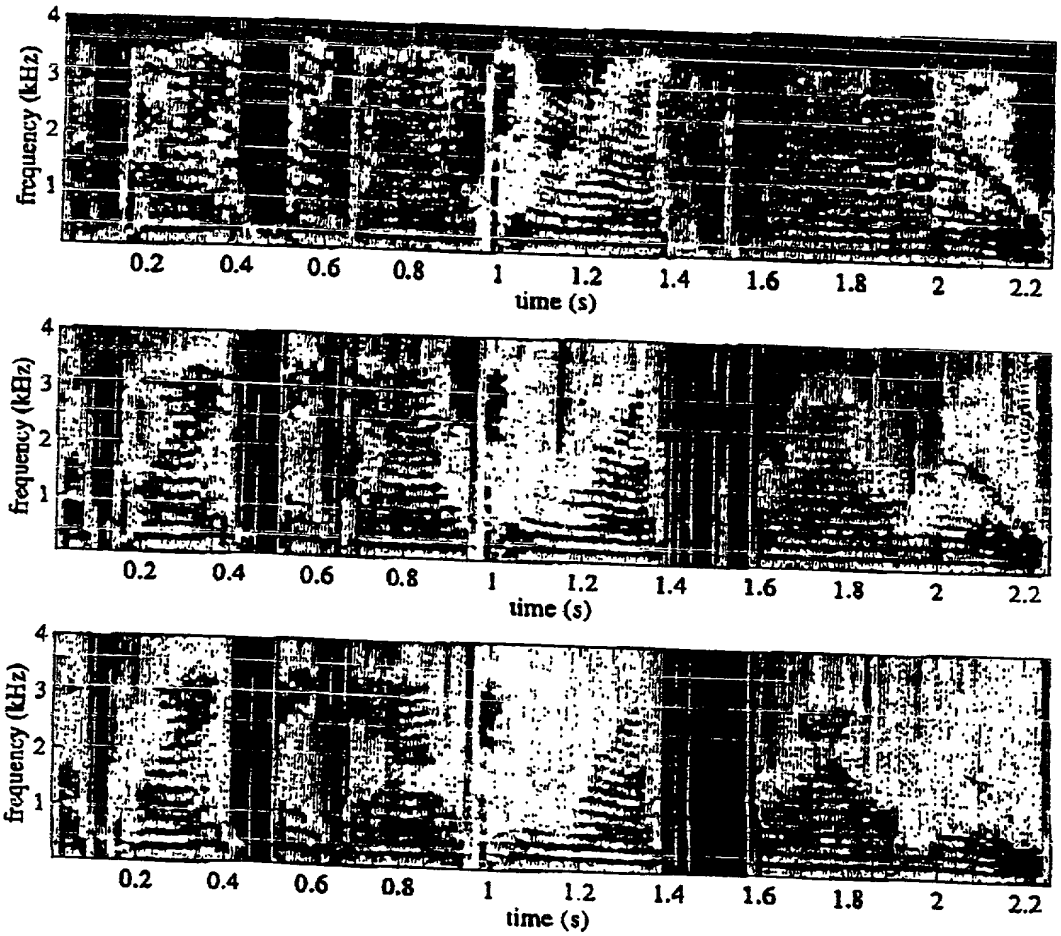

Fig 9

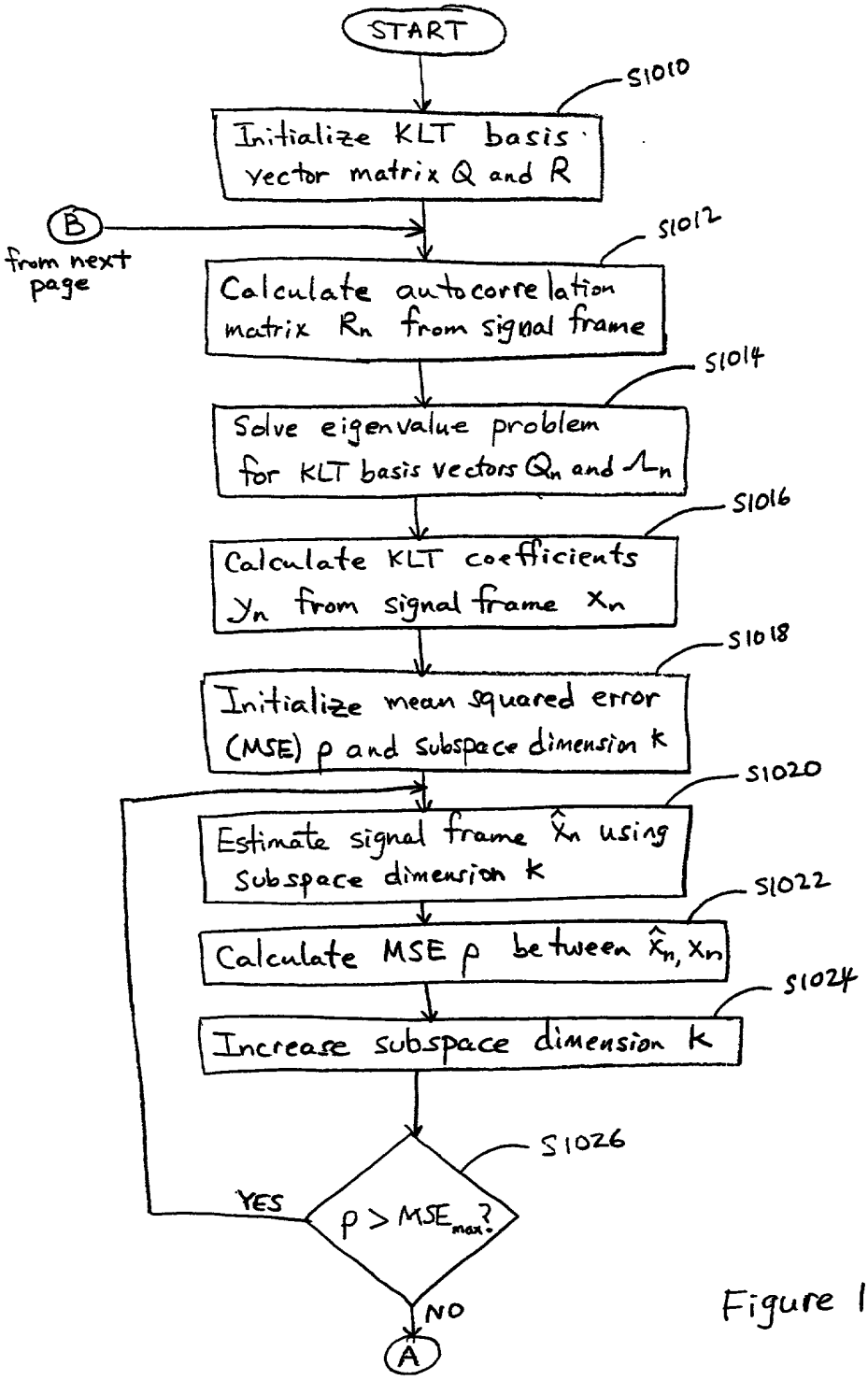
START
S1010
Initialize KLT basis vector matrix Q and R
B
from next page
S1012
Calculate autocorrelation matrix R_n from signal frame
S1014
Solve eigenvalue problem for KLT basis vectors Q_n and Λ_n
S1016
Calculate KLT coefficients y_n from signal frame x_n
S1018
Initialize mean squared error (MSE) ρ and subspace dimension k
S1020
Estimate signal frame $\hat{x}_n$ using subspace dimension k
S1022
Calculate MSE ρ between $\hat{x}_n, x_n$
S1024
Increase subspace dimension k
S1026
YES
$\rho > MSE_{max}$?
NO
A

Figure 10A

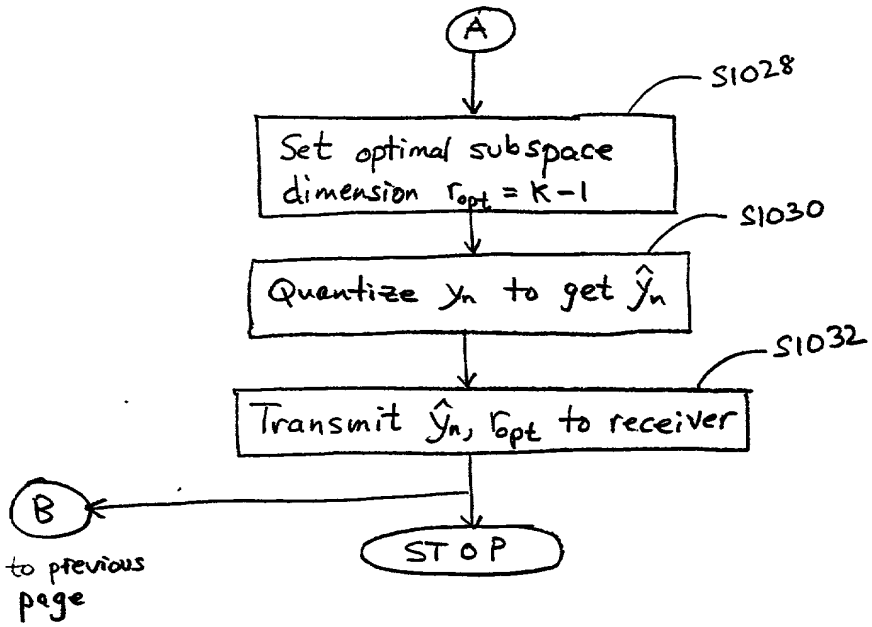

Figure 10A (cont.)

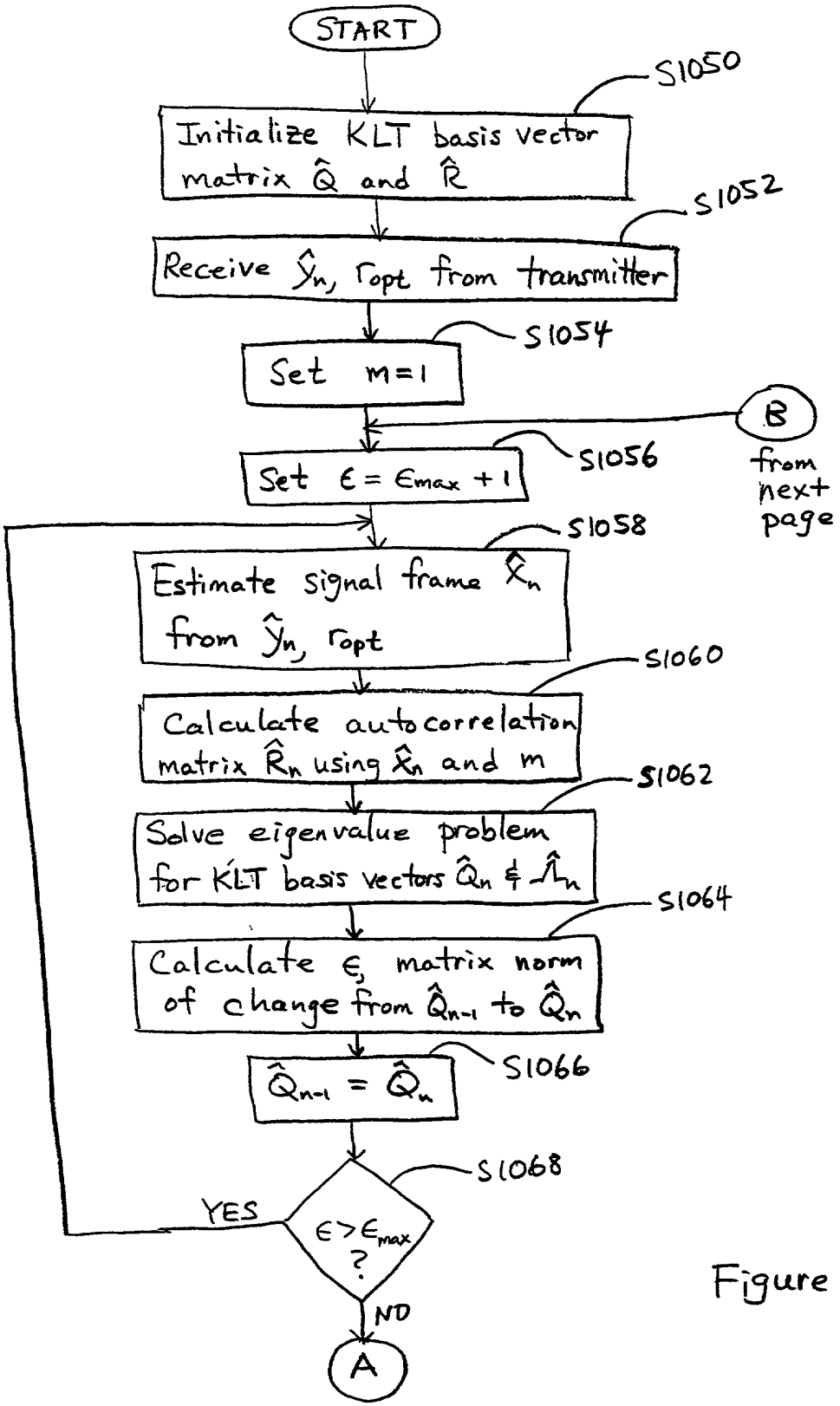
START
S1050
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{R}$
S1052
Receive $\hat{y}_n$, r_{opt} from transmitter
S1054
Set m=1
B
from next page
S1056
Set $\epsilon = \epsilon_{max} + 1$
S1058
Estimate signal frame $\hat{x}_n$ from $\hat{y}_n$, r_{opt}
S1060
Calculate autocorrelation matrix $\hat{R}_n$ using $\hat{x}_n$ and m
S1062
Solve eigenvalue problem for KLT basis vectors $\hat{Q}_n$ & $\hat{\Lambda}_n$
S1064
Calculate ϵ, matrix norm of change from $\hat{Q}_{n-1}$ to $\hat{Q}_n$
S1066
$\hat{Q}_{n-1} = \hat{Q}_n$
S1068
$\epsilon > \epsilon_{max}$?
YES
NO
A

Figure 10B

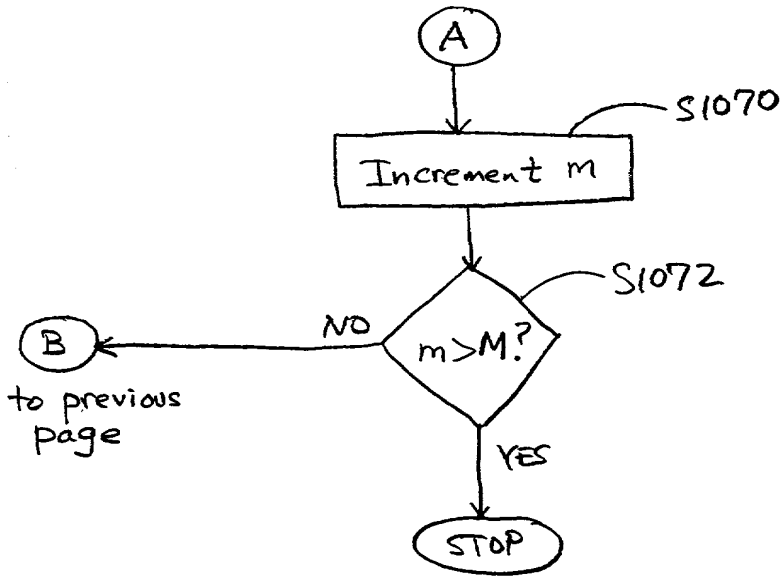

Figure 10B (cont.)

transmitter

$Q_0 = I_N$
$R_0 = \beta I_N$
for $n=1, 2, \ldots$
  $R_n = \gamma R_{n-1} + x_n x_n^T$
  Solve $R_n Q_n = Q_n \Lambda_n$ for Q_n, Λ_n
  $y_n = Q_n^T x_n$
  $\rho = 1$
  $k = 1$
  while $\rho > MSE_{max}$
    $\hat{x}_n = Q_n(:, 1:k)\, y_n(1:k)$
    $\rho = \|\hat{x}_n - x_n\|^2 / \|x_n\|^2$
    $k = k+1$
  end
  $r_{opt} = k-1$
  $\hat{y}_n = \Delta(y_n)$
  transmit $\hat{y}_n, r_{opt}$ to receiver
end

receiver

$\hat{Q}_0 = I_N$
$\hat{R}_0 = \beta I_N$
for $n=1, 2, \ldots$
  wait for $\hat{y}_n, r_{opt}$
  $\alpha = 1/M$
  for $m = 1, .., M$
    $\epsilon = \epsilon_{max} + 1$
    while $\epsilon > \epsilon_{max}$
      $\hat{x}_n = \hat{Q}_{n-1}(:, 1:r_{opt})\, \hat{y}_n(1:r_{opt})$
      if $m=1$
        $\hat{R}_n = \gamma \hat{R}_{n-1} + \alpha \hat{x}_n \hat{x}_n^T$
      else
        $\hat{R}_n = \hat{R}_n + \alpha \hat{x}_n \hat{x}_n^T$
      end
      Solve $\hat{R}_n \hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}$
      $\epsilon = \|\hat{Q}_n - \hat{Q}_{n-1}\|$
      $\hat{Q}_{n-1} = \hat{Q}_n$
    end
  end
end

Figure 10c

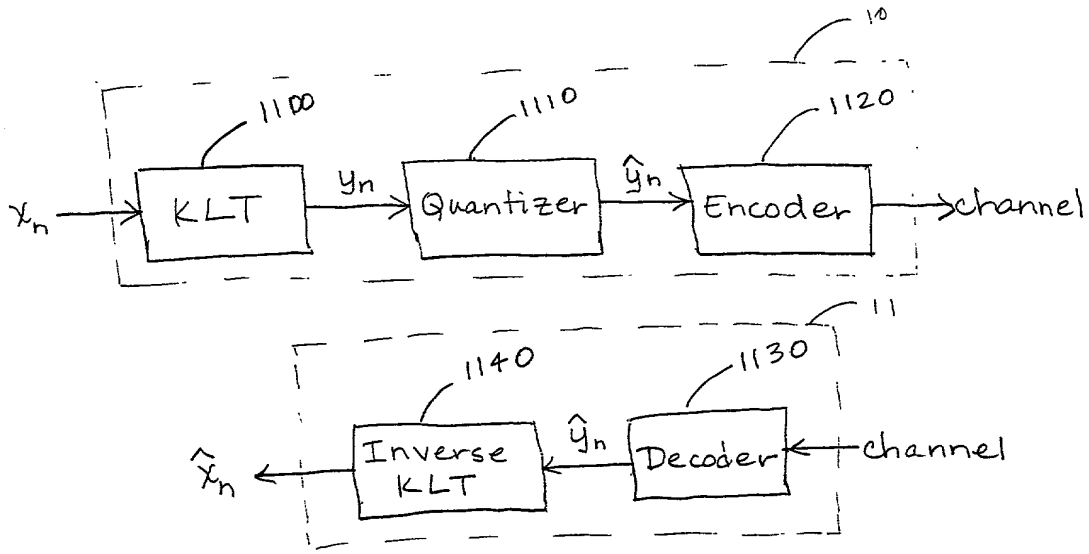
10
1100
1110
1120
x_n
KLT
y_n
Quantizer
$\hat{y}_n$
Encoder
channel
11
1140
1130
$\hat{x}_n$
Inverse KLT
$\hat{y}_n$
Decoder
channel

Fig. 11